

John - Harvard

1989

P 7

President and Fellows of Harvard College
c. o. Office for Sponsored Research
1350 Massachusetts Avenue, Room 458
Cambridge, MA 02138

Theoretical Research in Planetary Physics

Final Report, for the period 1973-1989

NASA grant NGR 22-007-269

Principal Investigator: A. G. W. Cameron

(NASA-CR-193492) THEORETICAL
RESEARCH IN PLANETARY PHYSICS Final
Report, 1973 - 1989 (Harvard
Univ.) 7 p

N93-72675

Unclassified

29/91 0179590

Summary

The research supported by NGR 22-007-269 has covered a wide range of topics all related to the problems of the origin of the solar system. Many different postdoctoral fellows at Harvard University and collaborators at other institutions, both with the postdoctoral fellows and with the principal investigator, have contributed to this research. The following is a summary bibliography.

Publications partially supported by NASA grant NGR 22-007-269

1. Podolak, M., and Cameron, A. G. W. (1974) "Models of the Giant Planets", *Icarus*, **322**, 123.
2. Perri, F., and Cameron, A. G. W. (1974) "Hydrodynamic Instability of the Solar Nebula in the Presence of a Planetary Core", *Icarus*, **322**, 416.
3. Tinsley, B. M., and Cameron, A. G. W. (1974) "Possible Influence of Comets on the Chemical Evolution of the Galaxy", *Astrophys. Space Sci.*, **331**, 31.
4. Podolak, M., and Cameron, A. G. W. (1974) "Possible Formation of Meteoritic Chondrules and Inclusions in the Precollapse Protoplanetary Jovian Atmosphere", *Icarus*, **323**, 326.
5. Ward, W. R. (1974) "Some Remarks on the Accretion Problem", Presented at the International Meeting on Planetary Physics and Geology, Academia Nazionale dei Lincei, Rome, April (1974).
6. Cameron, A. G. W. (1975) "Clumping of Interstellar Grains during Formation of the Primitive Solar Nebula", *Icarus*, **324**, 128.
7. Cameron, A. G. W. (1975) "The Role of Dust in Cosmogony", in *The Dusty Universe*, (G. B. Field and A. G. W. Cameron, eds.), Neal Watson Academic Publications, New York.
8. Podolak, M., and Cameron, A. G. W. (1975) "Further Investigations of Jupiter Models", *Icarus*, **325**, 627.
9. Ward, W. R. (1975) "Tidal Friction and Generalized Cassini's Laws in the Solar System", *Astron. J.*, **380**, 64.
10. Ward, W. R. (1975) "Cosmogony of the Solar System", *Rev. Geophys. Space Phys.*, **313**, 922.
11. Ward, W. R. (1975) "Past Orientation of the Lunar Spin State", *Science*, **3189**, 377.
12. Ward, W. R. (1976) "Formation of the Solar System", in *Frontiers of Astrophysics*, (E. Avrett, ed.), Harvard University Press, Cambridge.
13. Ward, W. R., Colombo, G., and Franklin, F. A. (1976) "Secular Resonance, Solar Spin Down and the Orbit of Mercury", *Icarus*, **328**, 441.
14. Cameron, A. G. W., and Pollack, J. B. (1976) "On the Origin of the Solar System and of Jupiter and its Satellites", in *Jupiter* (T. Gehrels, ed.), University of Arizona Press, p. 61.
15. Cameron, A. G. W. (1977) "Formation of the Outer Planets and Satellites", in *Planetary Satellites*, (J. A. Burns, ed.), University of Arizona Press.
16. Slattery, W. (1977) "The Structure of the Planets Jupiter and Saturn", *Icarus*, **332**, 58.
17. DeCampli, W. M., and Wright, E. (1977) "A New, Very Compact Far-Infrared Source in Sagittarius", *Bull. Am. Astron. Soc.*, **39**, 372.
18. Cameron, A. G. W., and Truran, J. W. (1977) "The Supernova Trigger for Formation of the Solar System", *Icarus*, **330**, 447.
19. Ward, W. R., and DeCampli, W. M. (1977) "Comments on the Venus Rotation Pole", *Bull. Am. Astron. Soc.*, **39**, 467.

20. Cameron, A. G. W. (1978) "The Primitive Solar Accretion Disk and the Formation of the Planets", in *The Origin of the Solar System*, (Dermott, ed.), Wiley & Sons, p. 49.
21. Cameron, A. G. W. (1978) "Physics of the Primitive Solar Accretion Disk", *The Moon and the Planets*, **318**, 5.
22. Cameron, A. G. W. (1978) "Physics of the Primitive Solar Nebula and of Giant Gaseous Protoplanets", in *Protostars and Planets*, (Tom Gehrels, ed.), University of Arizona Press, p. 453.
23. DeCampli, W. M., Cameron, A. G. W., Bodenheimer, P., and Black, D. C., (1978) "Ortho- and Para-Hydrogen in Dense Clouds, Protoplanets, and Planetary Atmospheres", *Astrophys. J.*, **3223**, 557.
24. DeCampli, W. M., and Baliunas, S. L. (1978) "What Tides and Flares Do to RS Dv Binaries", *Astrophys. J.*, **3230**, 815.
25. Wright, E. L., DeCampli, W. M., Fazio, G. G., Kleinmann, D. E., Lada, C. J., and Low, F. J. (1978). "Discovery of a Compact Far Infrared Source, IR 12.4 + 0.5", *Astrophys. J.*, **3228**, 439.
26. Slattery, Wayne L. (1978) "Protoplanetary Core Formation by Rain-Out of Iron Drops", *The Moon and the Planets*, **319**, 4, 443.
27. A'Hearn, M. F., and Cowan, J. J. (1978) "Evaporation Lifetimes of Comets", *Bull. Am. Astron. Soc.*, **310**, 613.
28. DeCampli, W. M., and Cameron, A. G. W. (1979) "Structure and Evolution of Isolated Giant Gaseous Protoplanets", *Icarus*, **338**, 367.
29. Cowan, J. J., and A'Hearn, M. F. (1979). "Vaporization of Comet Nuclei: Light Curves and Lifetimes", *The Moon and the Planets*, **321**, 155.
30. A'Hearn, M. F., and Cowan, J. J., (1979). "Vaporization in Comets: The Icy Grain Halo of Comet West", *The Moon and the Planets*, **323**, 41.
31. A'Hearn, M. F., and Cowan, J. J., (1979) "Evidence for Two Different Ices in Comet West", *Bull. Am. Astron. Soc.*, **311**, 455.
32. Consolmagno, G. J. (1979) "Sulfur Volcanoes on Io", *Science*, **3205**, 397.
33. Consolmagno, G. J. (1979) "Ree Patterns Versus the Origin of the Basaltic Achondrites", *Icarus*, **340**, 522.
34. Consolmagno, G. J., and Cameron, A. G. W. (1979) "The Nucleosynthesis Components of Isotopic Anomalies in Allende Inclusions", *Lunar and Planetary Science X*, p. 235.
35. Lewis, S. J., and Consolmagno, G. J. (1979) "Io: Geochemistry and Geophysics of Sulfur", *Bull. Am. Astron. Soc.*, **311**, 599.
36. Consolmagno, G. J., and Lewis, J. S. (1979) "The Evolution of Io", *Bull. Am. Astron. Soc.*, **311**, 599.
37. Ward, W. R. (1979) "Present Obliquity Oscillations of Mars: Fourth-Order Accuracy in Orbital e and I", *J. Geophys. Res.*, **384**, 237.
38. Ward, W. R., Burns, J. A., and Toon, O. B. (1979) "Past Obliquity Oscillations of Mars: The Role of the Tharsis Uplift", *J. Geophys. Res.*, **384**, 243.
39. Ward, W. R., and DeCampli, W. M. (1979) "Comments on the Venus Rotation Pole", *Astrophys. J. (Letters)*, **327**, 232.
40. Cameron, A. G. W. (1979) "The Interaction Between Giant Gaseous Protoplanets and the Primitive Solar Nebula", *The Moon and the Planets*, **321**, 173.
41. Cameron, A. G. W. (1979) "On the Origin of Asteroids", in *Asteroids*, (Tom Gehrels, ed.), University of Arizona Press, p. 992.

42. Consolmagno, G. J., and Cameron, A. G. W. (1980) "The Origin of the FUN Anomalies and the High Temperature Inclusions in the Allende Meteorite", *The Moon and the Planets*, **323**, 3.
43. Consolmagno, G. J. (1980) "Influence of the Interplanetary Magnetic Field on Cometary and Primordial Dust Orbits: Applications of Lorentz Scattering", *Icarus*, **343**, 203.
44. Consolmagno, G. J. (1980) "Electromagnetic Scattering Lifetimes for Dust in Jupiter's Ring", *Nature*, **3285**, 557.
45. Slattery, W. L., DeCampli, W. M., and Cameron, A. G. W. (1980) "Protoplanetary Core Formation by Rain-Out of Minerals", *The Moon and the Planets*, **323**, 381.
46. Cameron, A. G. W., DeCampli, W. M., and Bodenheimer, P. H. (1980) Numerical Experiments with Giant Gaseous Protoplanets Embedded in the Primitive Solar Nebula", *Lunar and Planetary Science XI*, p. 122.
47. Prinn, R. G., and Fegley, M. B., Jr. (1981) "Kinetic Inhibition of CO and N₂ Reduction in Circumplanetary Nebulae: Implications for Satellite Composition". *Astrophys. J.*, **3249**, 308.
48. Consolmagno, G. J. (1981) "Io: Thermal Models and Chemical Evolution", *Icarus*, **347**, 36.
49. Consolmagno, G. J. (1981) "An Io Thermal Model with Intermittent Volcanism", *Lunar and Planetary Science XII*, p. 175.
50. Consolmagno, G. J. (1981) "An Io Thermal Model with Intermittent Volcanism", *Proc. Lunar Planet. Sci. Conf. 12th*, p. 1533.
51. Cameron, A. G. W., DeCampli, W. M., and Bodenheimer, P. H. (1981). "Thermal Evaporation of Giant Gaseous Protoplanets", *Lunar and Planetary Science XII*, p. 123.
52. Fegley, M. B., Jr. (1981) "Nitrogen Thermochemistry in Solar Composition Material", *Meteoritics*, **316**, 314.
53. Fegley, M. B., Jr. (1981) "The Thermodynamic Properties of Silicon Oxynitride", *J. Amer. Ceram. Soc.*, **364**, C124.
54. Fegley, M. B., Jr. (1982) "Hibonite Condensation in the Solar Nebula", *Lunar and Planetary Science XIII*, p. 211.
55. Cameron, A. G. W., and Fegley, M. B., Jr. (1982) "Condensation Events Near the Total Evaporation Front Within the Primitive Solar Nebula", *Lunar and Planetary Science XIII*, p. 81.
56. Lewis, J. S., and Fegley, M. B., Jr. (1982) "Venus: Halide Cloud Condensation and Volatile Element Inventories", *Science*, **3216**, 1223.
57. Fegley, M. B., Jr. (1982) "Nitrogen Retention in Ordinary Chondrites", *EOS Trans. AGU*, **363**, 364.
58. Cameron, A. G. W., and Fegley, M. B., Jr. (1982) "Condensation Events Near the Total Evaporation Front Within the Primitive Solar Nebula", *Lunar and Planetary Science XIII*, p. 81.
59. Cameron, A. G. W., DeCampli, W. M., and Bodenheimer, P. H. (1982) "Evolution of Giant Gaseous Protoplanets Embedded in the Primitive Solar Nebula", *Icarus*, **349**, 298.
60. Fegley, M. B., Jr. (1982) "Primordial Retention of Nitrogen by Meteorites and the Terrestrial Planets and Meteorites", *Proc. Lunar Planet. Sci. Conf. 13th, J. Geophys. Res.*, **388A**, 853.
61. Cameron, A. G. W., and Fegley, M. B., Jr. (1982) "Nucleation and Condensation in the Primitive Solar Nebula", *Icarus*, **352**, 1.

62. Fegley, M. B., Jr. (1982) "Thermodynamic Properties of Metastable CaO-Al₂O₃ Liquids", *Bull. Amer. Ceram. Soc.*, **36**, 808.
63. Fegley, M. B., Jr. (1982) "Chemical Fractionation in Enstatite Chondrites", *Meteoritics*, **317**, 210.
64. Fegley, M. B., Jr., Hartman, H., and Prinn, R. G. (1982) "Effects of Large Impacts on Evolution of the Earth's Earliest Atmosphere", *EOS Trans. AGU*, **363**, 1018, (abstract).
65. Fegley, M. B., Jr. (1982) "A Condensation-Accretion Model for Volatile Element Retention", *Conference on Planetary Volatiles, LPI Contribution 488*, p. 37.
66. Fegley, M. B., Jr., and Kornacki, A. S. (1982) "Spinel-Rich Chondrules and the Condensation of Metastable Liquids in the Solar Nebula," *Conference on Chondrules and their Origins, LPI Contribution 493*, p. 16.
67. Cameron, A. G. W. (1982) "Compositional Clues to the History of the Terrestrial Planet Atmospheres", *Conference on Planetary Volatiles, LPI Contribution 488*, p. 16.
68. Cameron, A. G. W. (1982) "Chondrule Related Processes in the Primitive Solar Nebula", *Conference on Chondrules and their Origins, LPI Contribution 493*, p. 9.
69. Cameron, A. G. W., and Mercer-Smith, J. A. (1983) "Behavior of the Sun during Growth from the Primitive Solar Nebula", *Lunar and Planetary Science XIV*, p. 88.
70. Fegley, M. B., Jr., and Prinn, R. G. (1983) "Chemical Probes of Saturn's Deep Atmosphere", *Lunar and Planetary Science XIV*, p. 189.
71. Fegley, M. B., Jr., and Kornacki, A. S. (1983) "The Geochemical Behavior of Refractory Noble Metals and Lithophile Trace Elements in CAI's", *Lunar and Planetary Science XIV*, p. 187.
72. Hartman, H., Fegley, M. B., Jr., Prinn, R. G., and Lewis, J. S. (1983) "Organic Molecules and Carbonaceous Chondrites", *Lunar and Planetary Science XIV*, p. 279.
73. Cameron, A. G. W. (1983) "Dissipation of Thick Accretion Disks", *Astrophysics and Space Science*, **93**, 295.
74. Cameron, A. G. W. (1983) "Origin of the Atmospheres of the Terrestrial Planets", *Icarus*, **56**, 105.
75. Fegley, M. B., Jr. (1983) "The Stability of Refractory Noble Metal-Lithophile Alloys in Enstatite Chondrites and Aubrites", *Meteoritics*, **18**, 296.
76. Kornacki, A. S., and Fegley, M. B., Jr. (1984) "Origin of Spinel-Rich Chondrules and Inclusions in Carbonaceous and Ordinary Chondrites", *Proc. Lunar Planet. Sci. Conf. 14th, J. Geophys. Res.*, **89**, B588-596.
77. Fegley, M. B., Jr., and Kornacki, A. S. (1984) "The Geochemical Behavior of Refractory Noble Metals and Lithophile Trace Elements in Calcium-Aluminum Inclusions", *Earth Planet. Sci. Lett.*, **68**, p.181.
78. Cabot, W. (1984) "The Nonaxisymmetric Baroclinic Instability in Thin Accretion Disks", *Astrophys. J.*, **277**, 806.
79. Cameron, A. G. W. (1984) "Star Formation and Extinct Radioactivities", *Icarus*, **60**, 416.
80. Cameron, A. G. W. (1984) "Formation of the Prelunar Accretion Disk", *Conference on the Origin of the Moon*, LPI, Kona, Hawaii (abstract).
81. Cameron, A. G. W. (1984) "The Rapid Dissipation Phase of the Primitive Solar Nebula", *Lunar and Planetary Science XV*, The Lunar and Planetary Institute, Houston, TX, p. 118.
82. Cameron, A. G. W. (1985) "Conditions During Formation of the Earth", *Workshop on the Early Earth*, LPI, Houston, TX (abstract).
83. Cameron, A. G. W. (1985) "The Loss of Mantle material from Mercury." *Lunar*

- and Planetary Science XVI*, The Lunar and Planetary Institute, Houston, TX, p. 105 (abstract).
84. Mercer-Smith, J. A., and Cameron, A. G. W. (1985) "On the Persistence of a Rotating Protostellar Core", *Bull. Am. Phys. Society*, **30**, 716.
 85. Cameron, A. G. W. (1985) "Formation of the Prelunar Accretion Disk", *Icarus*, **62**, 319.
 86. Cameron, A. G. W. (1985) "Formation and Evolution of the Primitive Solar Nebula", in *Protostars and Planets II*, ed. D. Black and M. S. Matthews, University of Arizona Press.
 87. Cameron, A. G. W. (1985) "The Partial Volatilization of Mercury", *Icarus*, **64**, 285.
 88. Cameron, A. G. W. (1985) "On Bipolar Ejection", *Astrophys. J. (Letters)*, **299**, L83.
 89. Slattery, W. L., Benz, W., Hotchkiss, R. S., and Cameron, A. G. W. (1985) "The Origin of the Moon and the Single Impact Hypothesis I", *Bull. Am. Astron. Soc.*, **17**, 713.
 90. Benz, W., Slattery, W. L., and Cameron, A. G. W. (1985) "The Origin of the Moon and the Single Impact Hypothesis II", *Bull. Am. Astron. Soc.*, **17**, 726.
 91. Fegley, M. B., Jr., Prinn, R. G., Hartman, H., and Watkins, G. H. (1986) "Chemical Effects of Large Impacts on the Earth's Primitive Atmosphere", *Nature*, **319**, 305.
 92. Cameron, A. G. W., and Fegley, Jr., M. B. (1986) "Density and Composition of the Mercury Mantle After Evaporative Mass Loss", *Lunar and Planetary Science XVII*, Lunar and Planetary Institute, Houston, TX.
 93. Benz, W., Slattery, W. L., and Cameron, A. G. W. (1986) "The Origin of the Moon: 3D Numerical Simulations of a Giant Impact", *Lunar and Planetary Science XVII*, Lunar and Planetary Institute, Houston, TX.
 94. Cameron, A. G. W. (1986) "The Impact Theory for Origin of the Moon", in *Origin of the Moon*, ed. W. K. Hartmann, R. J. Phillips, and G. J. Taylor, Lunar and Planetary Institute, Houston, TX.
 95. Benz, W., Slattery, W. L., and Cameron, A. G. W. (1986) "Brief Note: Snapshots from a 3-Dimensional Modeling of a Giant Impact", in *Origin of the Moon*, ed. W. K. Hartmann, R. J. Phillips, and G. J. Taylor, Lunar and Planetary Institute, Houston, TX.
 96. Benz, W., Slattery, W. L., and Cameron, A. G. W. (1986) "The Origin of the Moon and the Single Impact Hypothesis I.", *Icarus*, **66**, 515–535.
 97. Fegley, Jr., B., and Cameron, A. G. W. (1987) "A Vaporization Model for Iron/Silicate Fractionation in the Mercury Protoplanet", *Earth Planet. Sci. Lett.*, **82**, 207–222.
 98. Benz, W., Cameron, A. G. W., and Slattery, W. L. (1987) "Planetary Collision Calculations: Origin of the Moon", *Lunar and Planetary Science XVIII*, Lunar and Planetary Institute, Houston, TX.
 99. Cameron, A. G. W., Benz, W., and Slattery, W. L. (1987) "Planetary Collision Calculations: Origin of Mercury", *Lunar and Planetary Science XVIII*, Lunar and Planetary Institute, Houston, TX.
 100. Benz, W., Slattery, W. L., and Cameron, A. G. W. (1987) "The Origin of the Moon and the Single Impact Hypothesis II.", *Icarus*, **71**, 30–45.
 101. Wasson, J. T., Rubin, A. E., and Benz, W. (1987) "Heating of Primitive, Asteroid-Size Bodies by Large Impacts", *Meteoritics*, **22**, 525–526.
 102. Benz, W., Cameron, A. G. W., and Slattery, W. L. (1988) "Collisional Stripping of Mercury's Mantle", *Icarus*, **74**, 516–528.
 103. Benz, W. (1988) "Applications of Smooth Particle Hydrodynamics (SPH) to Astro-physical Problems", *Computer Phys. Comm.*, **48**, 97–105.

104. Cameron, A. G. W., Fegley, Jr., B., Benz, W., and Slattery, W. L. (1988) "The Strange Density of Mercury: Theoretical Considerations", in *Mercury*, ed. by F. Vilas, C. R. Chapman, and M. S. Matthews, University of Arizona Press.
105. Cameron, A. G. W. (1988) "Origin of the Solar System", *Annual Review of Astronomy and Astrophysics*, **26**, 441 (1988).
106. Benz, W., Cameron, A. G. W., and Melosh, H. J. (1988) "The Origin of the Moon: Further Studies of the Giant Impact", *Lunar and Planetary Science XIX*, Lunar and Planetary Institute, Houston, TX.
107. Cameron, A. G. W., and Benz, W. (1988) "Effects of the Giant Impact on the Earth", abstract booklet for Conference on the Origin of the Earth, Berkeley.
108. Cannizzo, J. K., and Cameron, A. G. W. (1988) "On Convection-Induced Viscosity in Accretion Disks in Cataclysmic Variables", *Astrophysical Journal*, **330**, 327.
109. Cameron, A. G. W., and Benz, W. (1989) "Possible Scenarios Resulting From the Giant Impact", *Lunar and Planetary Science XX*, Lunar and Planetary Institute, Houston, TX.
110. Benz, W., Cameron, A. G. W., and Melosh, H. J. (1989) "The Origin of the Moon and the Single Impact Hypothesis III.", *Icarus*, **81**, 113.
111. Benz, W., Slattery, W. L., and Cameron, A. G. W. (1989) "Tilting Uranus in a Giant Impact", *Meteoritics*, **24**, 251.
112. Benz, W., Cameron, A. G. W., and Slattery, W. L. (1989) "Tilting Uranus in a Giant Impact", *Bulletin of the American Astronomical Society*, **21**, 916 (1989).
113. Benz, W., and A. G. W. Cameron (1990) "Terrestrial Effects of the Giant Impact", in *Origin of the Earth*, ed. H. E. Newsom and J. H. Jones, Oxford University Press, New York (1990).
114. Boss, A. P., Cameron, A. G. W., and Benz, W. (1990) "Tidal Disruption of Inviscid Protoplanets", *Lunar and Planetary Science XXI*, Lunar and Planetary Institute, Houston, TX (1990).
115. Cameron, A. G. W., Benz, W., and Wasson, J. T. (1990) "Heating During Asteroidal Collisions", *Lunar and Planetary Science XXI*, Lunar and Planetary Institute, Houston, TX (1990).
116. Boss, A. P., A. G. W. Cameron, and W. Benz (1991) "Tidal Dissipation of Inviscid Planetesimals", *Icarus*, **92**, 165.
117. Cameron, A. G. W., and W. Benz (1991) "The Origin of the Moon and the Single Impact Hypothesis IV", *Icarus*, **92**, 204.